CLAIMS

1. Reflectometry apparatus, comprising:

a radiation source, adapted to irradiate a sample with radiation over a range of angles relative to a surface of the sample;

a detector assembly, positioned to receive the radiation reflected from the sample over the range of angles and to generate a signal responsive thereto; and

a shutter, adjustably positionable to intercept the radiation, the shutter having a blocking position, in which it blocks the radiation in a lower portion of the range of angles, thereby allowing the reflected radiation to reach the array substantially only in a higher portion of the range, and a clear position, in which the radiation in the lower portion of the range reaches the array substantially without blockage.

2. Apparatus according to claim 1, wherein the radiation comprises X-ray radiation, and wherein the lower portion of the range comprises angles below a critical angle for total external reflection of the radiation from the surface.

3. Apparatus according to claim 1, wherein the reflected radiation is characterized by a variation of intensity as a function of the angle due to the thin film layers, and wherein when the shutter is in the blocking position, the signal generated by the detector assembly responsive to the reflected radiation in the higher portion of the range of angles has a reduced background level relative to the background level when the shutter is in the clear position.

4. Apparatus according to claim 3, wherein the sample comprises one or more thin film layers, and wherein the variation of intensity comprises an oscillatory pattern.

5. Apparatus according to claim 4, and comprising a processor, which is coupled to receive the signal from the detector assembly and to analyze the oscillatory pattern to determine one or more properties of the one or more thin film layers.

6. Apparatus according to claim 5, wherein the oscillatory pattern comprises an initial shoulder occurring near a critical angle for total external reflection of the radiation from an outer one of the thin film layers at the surface of the sample, and wherein the one or more properties comprises a density of the outer thin film layer, such that the processor is adapted to estimate the density of the outer thin film layer responsive to the shoulder, irrespective of any other one of the properties.

7. Apparatus according to claim 5, wherein the detector assembly comprises an array of detector elements, and wherein the signal is indicative of respective charges accumulated by the detector elements due to photons of the radiation that are incident on the elements, and wherein the processor is adapted to estimate, responsive to the respective charges, a number of the photons that was incident on each of the elements.

8. Apparatus according to claim 7, wherein the processor is adapted to determine, responsive to the signal, whether a high flux of the photons or a low flux of the photons was incident on each of the elements, and to estimate the number of photons incident on each of the

elements by dividing the charges accumulated by the elements on which the high flux was incident by a high-flux average charge, and dividing the charges accumulated by the elements on which the low flux was incident by a low-flux average charge, substantially different from the high-flux average charge.

9. Apparatus according to claim 3, wherein the detector assembly is adapted to receive the radiation over a first integration period while the shutter is in the clear position and over a second integration period, substantially longer than the first integration period, while the shutter is in the blocking position, and comprising a processor, which is coupled to receive the signal from the detector assembly and to combine the signal generated by the detector assembly during the first integration period with the signal generated by the detector assembly during the second integration period so as to reconstruct the variation of the intensity over the entire range of angles.

10. Apparatus according to claim 1, wherein the detector assembly comprises an array of detector elements, including a first element positioned to receive the radiation reflected from the sample in the lower portion of the range of angles and a last element positioned to receive the radiation reflected from the sample in the higher portion of the range of angles.

11. Apparatus according to claim 10, wherein the detector assembly comprises a readout circuit and a charge coupled device (CCD), which has an output connected to the readout circuit and is coupled to transfer charges generated by the detector elements

responsive to the radiation from the detector elements to the output in sequence along the array beginning with the last element.

12. Apparatus according to claim 10, wherein the array has a length from the first element to the last element, and wherein the detector assembly comprises an evacuable enclosure having a front side and a rear side separated by a distance that is at least equal to the length of the array, wherein the array is positioned at the rear side of the enclosure, and the enclosure comprises a window at a front side thereof, which is adapted to allow the reflected radiation to pass therethrough.

13. Apparatus according to claim 1, wherein the radiation source is adapted to irradiate a spot on the sample, and comprising a knife edge, adjustably positionable to block a portion of the radiation while the shutter is in the clear position, so as to reduce a dimension of the spot.

14. Apparatus according to claim 13, wherein the radiation comprises X-ray radiation, and wherein the range comprises angles in a vicinity of a critical angle for total external reflection of the radiation from the surface, and wherein the knife edge is positionable so as to reduce the dimension of the spot to no more than 1 mm.

15. Radiation sensing apparatus, comprising:

a detector assembly, comprising an array of detector elements, positioned to receive X-ray photons emitted over a range of angles and to generate a signal indicative of respective charges accumulated by the detector elements due to the photons that are incident on the elements; and

a processor, which is coupled to receive the signal from the detector assembly and to determine, responsive to the signal, whether a high flux of the photons or a low flux of the photons was incident on each of the elements, and to estimate the number of photons incident on each of the elements by dividing the charges accumulated by the elements on which the high flux was incident by a high-flux average charge, and dividing the charges accumulated by the elements on which the low flux was incident by a low-flux average charge, substantially different from the high-flux average charge.

16. Apparatus according to claim 15, wherein the low flux is considered to be incident on one of the elements when no more than a single one of the photons is incident on the element over a period during which the charges are accumulated.

17. Apparatus according to claim 16, wherein for the elements on which the low flux was incident, the processor is adapted to divide the charges accumulated by a mutually-adjacent pair of the elements by the low-flux average charge, so as to determine whether one of the photons was incident on one of the elements in the pair.

18. Apparatus according to claim 15, wherein the detector assembly is adapted to receive the X-ray photons reflected by a sample over the range of angles, characterized by a variation of flux of the reflected photons as a function of angle, such that the high flux is incident on the elements in a low-angle portion of the range, and the low flux is incident on the elements in a high-angle portion of the range.

19. A detector assembly, comprising:

an array of detector elements, positioned to receive radiation and to generate a signal responsive thereto, the array including a first element and a last element and having a length defined by a distance between the first and last elements; and

an evacuable enclosure having a front side and a rear side separated by a distance that is at least equal to the length of the array, wherein the array is positioned at the rear side of the enclosure, and the enclosure comprises a window at a front side thereof, which is adapted to allow the radiation to pass therethrough so as to impinge on the array.

20. An assembly according to claim 19, wherein the front and rear sides of the enclosure are separated by a distance of at least twice the length of the array.

21. An assembly according to claim 19, wherein the radiation is emitted from a sample outside the enclosure.

22. An assembly according to claim 21, wherein the radiation comprises X-rays reflected from the sample over a range of angles, such that the first element receives the radiation reflected from the sample in a lower portion of the range of angles and the last element receives the radiation reflected from the sample in a higher portion of the range of angles.

23. An assembly according to claim 22, wherein the detector assembly comprises a readout circuit and a charge coupled device (CCD), which has an output connected to the readout circuit and is coupled to transfer charges generated by the detector elements responsive to the radiation from the detector elements to

the output in sequence along the array beginning with the last element.

24. A method for reflectometry, comprising:

irradiating a sample with radiation over a range of angles relative to a surface of the sample;

receiving the radiation reflected from the sample over the range of angles so as to generate a low-range signal responsive to the radiation reflected in a lower portion of the range;

blocking a lower part of the range of angles, thereby allowing the reflected radiation to reach the array substantially only in a higher portion of the range;

receiving the radiation reflected from the sample over the range of angles while the lower portion of the range is blocked, so as to generate a high-range signal responsive to the radiation reflected in a higher portion of the range; and

combining the high-range and low-range signals to determine a pattern of the reflected radiation over the range of angles, including both the lower and higher portions.

25. A method according to claim 24, wherein the radiation comprises X-ray radiation, and wherein the lower portion of the range comprises angles below a critical angle for total external reflection of the radiation from the surface.

26. A method according to claim 24, wherein the reflected radiation is characterized by a variation of intensity as a function of the angle due to the thin film layers, and wherein receiving the radiation while the

lower portion of the range of angles is blocked comprises generating the high-range signal with a reduced background level relative to the background level when the lower portion of the range is not blocked.

27. A method according to claim 26, wherein the sample comprises one or more thin film layers, and wherein the variation of intensity comprises an oscillatory pattern.

28. A method according to claim 27, and comprising analyzing the oscillatory pattern to determine one or more properties of the one or more thin film layers.

29. A method according to claim 28, wherein the oscillatory pattern comprises an initial shoulder occurring near a critical angle for total external reflection of the radiation from an outer one of the thin film layers at the surface of the sample, and wherein determining the one or more properties comprises estimating a density of the outer thin film layer responsive to the shoulder, irrespective of any other one of the properties.

30. A method according to claim 24, wherein the detector assembly comprises an array of detector elements, and wherein the signal is indicative of respective charges accumulated by the detector elements due to photons of the radiation that are incident on the elements, and wherein combining the signals comprises estimating, responsive to the respective charges, a number of the photons that was incident on each of the elements.

31. A method according to claim 30, wherein estimating the number of the photons comprises:

determining, responsive to the signals, whether a high flux of the photons or a low flux of the photons was incident on each of the elements;

dividing the charges accumulated by the elements on which the high flux was incident by a high-flux average charge; and

dividing the charges accumulated by the elements on which the low flux was incident by a low-flux average charge, substantially different from the high-flux average charge.

32. A method according to claim 24, wherein receiving the radiation so as to generate the low-range signal comprises receiving the radiation over a first integration period, and wherein receiving the radiation so as to generate the high-range signal comprises receiving the radiation over a second integration period, substantially longer than the first integration period.

33. A method according to claim 24, wherein receiving the radiation comprises receiving the radiation at an array of detector elements, including a first element positioned to receive the radiation reflected from the sample in the lower portion of the range of angles and a last element positioned to receive the radiation reflected from the sample in the higher portion of the range of angles, and transferring charges generated responsive to the radiation from the detector elements in sequence out of the array beginning with the last element.

34. A method according to claim 24, wherein receiving the radiation comprises:

receiving the radiation at an array of detector elements contained in an enclosure, the array including a first element and a last element defining a length of the array therebetween, the enclosure having a window defining a front side thereof, which is adapted to allow the reflected radiation to pass therethrough, and which is positioned at a distance from the array that is at least equal to the length of the array; and

evacuating the enclosure containing the array while receiving the radiation.

35. A method according to claim 24, wherein irradiating the sample comprises irradiating a spot on the sample, and while receiving the radiation so as to generate the low-range signal, cutting off a portion of the radiation so as to reduce a dimension of the spot.

36. A method according to claim 35, wherein the radiation comprises X-ray radiation, and wherein the range of angles comprises angles in a vicinity of a critical angle for total external reflection of the radiation from the surface, and wherein cutting off the portion of the radiation comprises positioning a knife edge adjacent to the surface so as to reduce the dimension of the spot to no more than 1 mm.

37. A method for sensing radiation, comprising:

receiving X-ray photons emitted over a range of angles at an array of detector elements, so as to generate a signal indicative of respective charges accumulated by the detector elements due to the photons that are incident on the elements; and

determining, responsive to the signal, whether a high flux of the photons or a low flux of the photons was incident on each of the elements;

estimating the number of photons incident on each of the elements on which the high flux was incident by dividing the charges accumulated by the elements by a high-flux average charge; and

estimating the number of photons incident on each of the elements on which the low flux was incident by dividing the charges accumulated by the elements by a low-flux average charge, substantially different from the high-flux average charge.

38. A method according to claim 37, wherein determining whether the high flux or the low flux was incident comprises determining that the high flux was incident on one of the elements when the charge accumulated by the element, not including a background charge, is at least three times the high-flux average charge.

39. A method according to claim 37, wherein determining whether the high flux or the low flux was incident comprises determining that the low flux was incident on one of the elements when no more than a single one of the photons was incident on the element over a period during which the charges were accumulated.

40. A method according to claim 37, wherein estimating the number of photons incident on each of the elements on which the low flux was incident comprises dividing the charges accumulated by a mutually-adjacent pair of the elements by the low-flux average charge, so as to determine whether one of the photons was incident on one of the elements in the pair.

41. A method according to claim 37, wherein receiving the X-ray photons comprises the X-ray photons reflected by a sample over the range of angles, characterized by a variation of flux of the reflected photons as a function of angle, such that the high flux is incident on the elements in a low-angle portion of the range, and the low flux is incident on the elements in a high-angle portion of the range.

42. A method for detecting radiation, comprising:

enclosing an array of detector elements in an enclosure, the array including a first element and a last element defining a length of the array therebetween, the enclosure having a window at a front side thereof, which is adapted to allow radiation to pass therethrough, and which is positioned at a distance from the array that is at least equal to the length of the array;

evacuating the enclosure containing the array; and

receiving the radiation at the array and generating a signal responsive thereto.

43. A method according to claim 42, wherein the distance from the array to the window is at least twice the length of the array.

44. A method according to claim 42, wherein receiving the radiation comprises receiving the radiation emitted from a sample outside the enclosure.

45. A method according to claim 44, wherein the radiation comprises X-rays reflected from the sample over a range of angles, such that the first element receives the radiation reflected from the sample in a lower portion of the range of angles and the last element receives the radiation reflected from the sample in a

higher portion of the range of angles, and wherein generating the signal comprises transferring charges generated at the detector elements responsive to the radiation to an output from the detector elements in sequence along the array beginning with the last element.

46. A method for reflectometry, comprising:

irradiating a sample comprising one or more thin film layers with radiation over a range of angles relative to a surface of the sample;

receiving the radiation reflected from the sample over the range of angles and generating a signal responsive to the reflected radiation, the signal having an oscillatory pattern as a function of the angle, the pattern comprising an initial shoulder occurring near a critical angle for total external reflection of the radiation from an outer one of the thin film layers at the surface of the sample; and

estimating a density of the outer thin film layer responsive to the shoulder, irrespective of any other properties of the one or more thin film layers.

47. A method according to claim 46 and comprising determining one or more of the other properties using the estimated density.

48. A method according to claim 47, wherein determining the one or more of the other properties comprises estimating a thickness of at least one of the layers.

49. A method according to claim 47, wherein determining the one or more of the other properties comprises estimating a surface roughness of at least one of the layers.